CHAPTER 4

DIAMOND SHAPED FRACTAL ANTENNAS

Chapter 4 presents the design and fabrication of the proposed diamond shaped fractal antenna. It also presents a discussion on the results obtained from the simulated and fabricated antenna.

4.1 Diamond shaped fractal antenna

In this chapter, a new diamond shaped fractal antenna has been presented to obtain multiband for wireless communication [197-198]. The proposed antenna is based on the Sierpinski Carpet fractal structure. The original Sierpinski Carpet is a deterministic fractal which is a generalization of the Cantor set in two dimensions. In order to construct this fractal, the process begins with a square in a plane. This square is subdivided into nine smaller congruent squares, out of which the central one is dropped. This process is continued by further sub dividing the remaining eight squares into nine smaller congruent squares in each of which the central one is again dropped. Thus, if this process is continued to infinity, then a limiting configuration can be obtained which can be seen as a generalization of the cantor set. The two key properties of fractal structure, viz. self-similarity and fractional dimensions, are evaluated by designing and fabricating the proposed diamond shaped fractal antenna, as follows.

4.2 Antenna design

The proposed multiband antenna is based on the Sierpinski Carpet fractal, as depicted in Fig. 4.1. The structure of this antenna is similar to the diamond; therefore, it is named (hereafter) diamond shaped fractal antenna. The dimensions of this diamond shaped antenna are 20mm × 30mm. In terms of wavelength, the antenna size is 0.322λ at the lowest frequency (where, λ = wavelength at resonant frequency). This antenna is first simulated and designed using the IE3D software. The designed antenna is fabricated using FR4 material of thickness d = 1.575mm with relative permittivity εr = 4.3 and loss tangent is 0.0009. The conductor is copper clad. The fabricated antenna is tested using site analyzer. In the design process two iterations have been performed.
To design the proposed diamond shaped antenna, the mathematical model used is explained below. The length of the antenna [199] is given by:

\[ L = \frac{c}{2f_r \sqrt{\varepsilon_{\text{eff}}}} - 2\Delta L \]  

(4.1)

where, \( c \) = speed of light in vacuum, \( f_r \) = resonant frequency, and \( \varepsilon_{\text{eff}} \) = effective permittivity, given by

\[ \varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left( \frac{1}{\sqrt{1 + 12 \frac{d}{W}}} \right) \]  

(4.2)

where, \( \varepsilon_r \) = relative permittivity, \( d \) = thickness of substrate and \( W \) = width. The width (\( W \)) is calculated using:

\[ W = \frac{c}{2f_r \sqrt{\varepsilon_r + 1}} \]  

(4.3)
Finally, the extended incremental length of patch is given by:

\[
\Delta L = 0.412d \frac{(\varepsilon_{\text{eff}} + 0.3)(\frac{W}{d} + 0.264)}{(\varepsilon_{\text{eff}} - 0.258)(\frac{W}{d} + 0.8)}
\]

(4.4)

Using the above equations, the designed antenna is fed coaxially at the location \(x = 2.025\text{mm}\) and \(y = 2.3\text{mm}\).

The proposed antenna is designed in two iterations. In the first iteration, using a scaling factor of 4, a diamond shaped structure with dimensions of 5mm \(\times\) 7.5mm has been designed and iterated on the existing main diamond structure. Fig. 4.2 shows the 1st iteration of the diamond shaped fractal antenna. During the second iteration, four diamond shapes of dimensions 1.25mm \(\times\) 1.875mm have been designed and iterated on the first iterated diamond structure. Fig. 4.3 shows the 2nd iteration of the diamond shaped fractal antenna. The final designed diamond shaped fractal antenna is shown in Fig. 4.4. The details of two design stages are presented below.

### 4.2.1 First iteration of diamond shaped fractal antenna

In the first iteration of designing the diamond shaped antenna, a scale factor of 4 is taken, so that a large area is occupied by the patch and it better satisfies the property of space-filling curves and self-similarity of fractals in the first stage. The first iteration of diamond shaped fractal antenna is designed by designing the smaller diamond shape structure of dimensions 5mm \(\times\) 7.5mm on the main diamond shaped structure and iterating it, as mentioned above. The scale factor is calculated as:

(VERTICAL CASE)

\[
\delta = \frac{h_n}{h_n + 1} - \frac{30}{7.5} - 4
\]

(4.5)

(HORIZONTAL CASE)

\[
\delta = \frac{h_n}{h_n + 1} = \frac{20}{5} = 4
\]

(4.6)

where, \(\delta = \) scaling factor, \(h = \) height of iterated antenna and \(n = \) iteration number. The results obtained for first iteration is shown in Fig. 4.2. The smaller diamond shape, shown in Fig. 4.2, is of dimensions 5mm \(\times\) 7.5mm with its x-axis and y-axis coordinates of four corners are (0, 3.75), (2.5, 0), (0, -3.75) and (-2.5, 0).

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4.2.2 Second iteration of diamond shaped fractal antenna

In the second iteration, by taking into account the properties of fractal structure viz. self-similarity, space-filling curves and fractional dimensions, the iterated function system is employed. The scale factor is calculated as:

(Vertical Case)

\[ \delta - \frac{h_n}{h_n + 1} = \frac{7.5}{1.875} - 4 \]

(Horizontal Case)

\[ \delta = \frac{h_n}{h_n + 1} = \frac{5}{1.25} = 4 \]

From the above results, it can be inferred that in the second iteration four smaller diamond shapes should be iterated in order to fulfil the criteria of structure to be fractal. All these four smaller diamond shapes are of equal area and of equal dimensions and are at each corner of the main structure as shown in Fig. 4.3. The dimensions of the 2\textsuperscript{nd} iterated diamond shape is 1.25mm × 1.875mm. These four diamonds are designed and iterated to finalize the second iteration.

The x-axis and y-axis coordinates of diamond shape antenna for 2\textsuperscript{nd} iteration are:

- (-6.875, 0), (-6.25, 0.9375), (-5.625, 0), (-6.25, -0.9375).
- (6.875, 0), (6.25, 0.9375), (6.25, -0.9375), (5.625, 0).
4.3 Antenna design parameters

4.3.1 Substrate

The substrate used to design proposed fractal antenna is FR4, with thickness \( d = 1.575 \text{mm} \), relative permittivity \( \varepsilon_r = 4.3 \) and loss tangent of 0.0009. The radiating element is copper clad. Its details are presented in Table 4.1.
Table 4.1: FR4 substrate parameters.

<table>
<thead>
<tr>
<th>Substrate used</th>
<th>FR 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>1.575mm</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>4.3</td>
</tr>
<tr>
<td>Loss tangent</td>
<td>0.0009</td>
</tr>
</tbody>
</table>

4.3.2 Antenna feeding

The diamond shape fractal antenna is coaxially fed at location $x = 2.025\text{mm}$ and $y = 2.3\text{mm}$ (Table 4.2) for second iteration.

Table 4.2: Port description.

<table>
<thead>
<tr>
<th>Port Used</th>
<th>Coaxial Probe Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>x coordinates</td>
<td>2.025mm</td>
</tr>
<tr>
<td>y coordinates</td>
<td>2.3mm</td>
</tr>
</tbody>
</table>

4.3.3 Antenna Structure used in simulator

IE3D electromagnetic simulator software is used to design and simulate the diamond shaped fractal antenna. The structure of the $2^{nd}$ iterated diamond shaped fractal antenna used in simulator is presented in Fig. 4.5.

Figure 4.5: Diamond shaped fractal antenna in simulator.

Fig. 4.6 depicts the picture of the fabricated antenna using FR4 substrate. The coaxial probe SMA connector is used to feed the antenna.
4.4 Results and discussions

4.4.1 Simulated and experimental results
To simulate the diamond shaped fractal antenna, IE3D electromagnetic simulator is used. As mentioned above, the antenna configuration with 2\textsuperscript{nd} iteration has been simulated. Fig. 4.7 depicts the simulated return loss characteristics of diamond shaped fractal antenna. This antenna operates at three resonant frequencies i.e. having centre frequency at 3.314GHz, 4.281GHz and 5.399GHz for 2\textsuperscript{nd} iteration.
Fig. 4.8 depicts the experimental set-up comprising site analyzer, which is used to test the fabricated antenna and Fig. 4.9 shows the measured return loss. The measured results also show the multiband behaviour of the antenna, as antenna resonates at 3.21GHz, 4.14GHz and 5.26GHz. As the iteration progresses, the resonance shifts downward and distinct multiband responses are observed due to the space-filling property. This result shows the frequency lowering phenomenon with the higher iteration order.

Figure 4.8: Experimental set-up to test the fabricated antenna.

Figure 4.9: Return loss measured with site analyzer.
The simulated gain-frequency plot of the antenna is shown above in Fig. 4.10. Three major resonant frequencies appeared at 3.31GHz, 4.28GHz and at 5.39GHz for the second iteration. The gains at respective resonant frequencies are 2.08dBi, 3.01dBi and 1.7dBi. The measured bandwidths are 110MHz, 170MHz and 112MHz respectively in these three frequency bands. The azimuth and elevation radiation patterns are simulated in the three resonant frequencies both at measured and simulated S11.

Fig. 4.11 depicts the simulated azimuth radiation pattern of the antenna. The simulation has been carried out at the three resonances as observed in the S11 measurement. The gains at these frequencies are within 3dB limit; thus, justifying multi-resonance characteristics. Fig. 4.12 and Fig. 4.13 respectively depicts the simulated elevation radiation patterns at the three resonances observed for both simulated and measured S11. These experimental and simulated results show that antenna behaviour is multiband in nature. With the increase in iteration order, resonant frequency gets lowered; thereby fulfilling the property of fractal antennas [198].
Figure 4.11: Azimuth radiation pattern of antenna at measured resonant frequencies.

Figure 4.12: Elevation radiation pattern of antenna at simulated resonant frequencies.
Figure 4.13: Elevation radiation pattern of antenna at measured resonant frequencies.

Fig. 4.14 depicts the directivity characteristics of the designed antenna. The directivity of the designed antenna is 6.4dBi, 6.5dBi and 8.2dBi at resonant frequency of 3.31GHz, 4.28GHz and 5.39GHz respectively.

Figure 4.14: Directivity characteristics of the designed antenna.
Fig. 4.15 depicts the VSWR characteristics of the designed antenna. The VSWR of designed antenna is 1.5, 1.2 and 1.6 at resonant frequency of 3.31GHz, 4.28GHz and 5.39GHz respectively.

The simulated results of 2nd iteration of diamond shaped fractal antenna are summarized in Table 4.3.

<table>
<thead>
<tr>
<th>Simulated Resonant Frequency (GHz)</th>
<th>Return loss (dB)</th>
<th>Gain (dBi) G</th>
<th>Directivity (dBi) D</th>
<th>Bandwidth (MHz)</th>
<th>% Bandwidth</th>
<th>VSWR</th>
<th>Efficiency Coefficient (k=G/D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.31</td>
<td>-14.09</td>
<td>2.08</td>
<td>6.4</td>
<td>110</td>
<td>33.23</td>
<td>1.5</td>
<td>0.325</td>
</tr>
<tr>
<td>4.28</td>
<td>-17.33</td>
<td>3.01</td>
<td>6.5</td>
<td>170</td>
<td>39.72</td>
<td>1.2</td>
<td>0.463</td>
</tr>
<tr>
<td>5.39</td>
<td>-28.9</td>
<td>1.7</td>
<td>8.2</td>
<td>112</td>
<td>20.78</td>
<td>1.6</td>
<td>0.207</td>
</tr>
</tbody>
</table>

4.5 Conclusion
In this chapter, a fractal antenna based on the Sierpinski Carpet fractal is designed and fabricated. The measured results of the fabricated antenna are compared with the simulated results. The azimuth and elevation radiation patterns are simulated at the measured and simulated resonant frequencies, which show a good degree of consistency. Thus, the proposed antenna has smaller dimensions and support multiband with considerable bandwidth, suitable for wireless communication.